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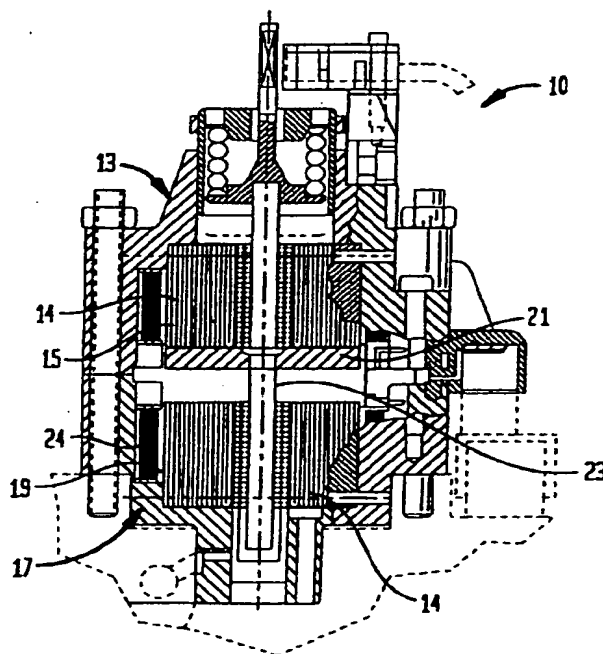
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(54) Electromagnetic actuator with lamination stack-housing dovetail connection

(57) A method of joining a lamination stack of an electromagnetic actuator to a housing of the actuator includes providing a lamination stack having at least one surface feature. A mold is provided to define the housing. The lamination stack is inserted into the mold such that the surface feature of the lamination stack will define a mating surface feature in the housing. Material is cast around at least a portion of lamination stack to define the housing such that the surface feature of the lamination stack is engaged with the surface feature of the housing, thereby joining the lamination stack to the housing. The assembly of the lamination stack and housing is then removed from the mold.

FIG. 1



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## Description

[0001] This application claims the benefit of U.S. Provisional Application No. 60/069,144, filed December 9, 1997, the contents of which is hereby incorporated by reference in its entirety herein.

## FIELD OF THE INVENTION

[0002] This invention relates to an electromagnetic actuator for a vehicle engine and, more particularly, to a method of securing a lamination stack of the actuator to a housing of the actuator.

## BACKGROUND OF THE INVENTION

[0003] A conventional electromagnetic actuator for opening and closing a valve of an internal combustion engine generally includes "open" and "close" electromagnets which, when energized, produce an electromagnetic force on an armature. The armature is biased by a pair of identical springs arranged in parallel. The armature is coupled with a cylinder valve of the engine. The armature rests approximately half-way between the open and close electromagnets when the springs are in equilibrium. When the armature is held by a magnetic force in either the closed or opened position (at rest against the open or close electromagnet), potential energy is stored by the springs. If the magnetic force is shut off with the armature in the opened position, the spring's potential energy will be converted to kinetic energy of the moving mass and cause the armature to move towards the close electromagnet. If friction is sufficiently low, the armature can then be caught in the closed position by applying current to the close electromagnet.

[0004] The conventional electromagnetic actuator includes a pair of electromagnets each including a lamination stack coupled to a housing. A coil is associated with each lamination stack. Typically, the lamination stack is secured to the housing by a pin connection which is generally difficult to install due to the forces required to create an interference fit with the housing.

[0005] There is a need to provide a lamination stack-housing connection which is easy to manufacture, allows a more rigid assembly, and provides intimate contact between the two components to facilitate heat transfer.

## SUMMARY OF THE INVENTION

[0006] An object of the present invention is to fulfil the need referred to above. In accordance with the principles of the present invention, this objective is obtained by a method of joining a lamination stack of an electromagnetic actuator to a housing of the actuator which includes providing a lamination stack having at least one shaped feature. A mold is provided to define the

housing. The lamination stack is inserted into the mold such that the shaped feature of the lamination stack will define a mating shaped feature in the housing. Material is cast around at least a portion of lamination stack to define the housing such that the shaped feature of the lamination stack is engaged with the shaped feature of the housing, thereby joining the lamination stack to the housing. The assembly of the lamination stack and housing is then removed from the mold.

[0007] In accordance with another aspect of the invention, a lamination stack and housing assembly for an electromagnetic actuator is provided which includes a lamination stack and a housing. The lamination stack has a plurality of individual laminations. The lamination stack also includes a bottom surface and a shaped feature associated with the bottom surface. The housing has an upper surface and a shaped feature associated with the upper surface. The housing receives the lamination stack such that the shaped feature of the lamination stack is engaged with the shaped feature of the housing and the bottom surface of the lamination stack contacts the upper surface of the housing.

[0008] Other objects, features and characteristic of the present invention, as well as the methods of operation and the functions of the related elements of the structure, the combination of parts and economics of manufacture will become more apparent upon consideration of the following detailed description and appended claims with reference to the accompanying drawings, all of which form a part of this specification.

## BRIEF DESCRIPTION OF THE DRAWINGS

### [0009]

FIG. 1 is a sectional view of an electromagnetic actuator having a housing-lamination stack connection provided in accordance with the principles of the present invention;

FIG. 2 is a perspective view of a lamination stack of the electromagnetic actuator of FIG. 1;

FIG. 3 is a perspective view of a cast lower housing of the electromagnetic actuator of FIG. 1, shown without the lamination stack coupled thereto; and

FIG. 4 is a cross-sectional view of the lamination stack of the actuator of FIG. 1, shown coupled to the lower housing after a casting operation.

## DETAILED DESCRIPTION OF THE INVENTION

[0010] Referring to FIG. 1, an electromagnetic actuator is shown, generally indicated 10, having a lower housing assembly and lamination stack connection provided in accordance with the principles of the present invention. The electromagnetic actuator 10 includes an upper housing 13 containing an upper electromagnet 15 and a lower housing 17 containing a lower electromagnet 19. An armature 21 is arranged for movement

between the electromagnets 15 and 19. The armature 21 is carried by a shaft 23. The shaft 23 is configured to be coupled to a stem of a cylinder valve (not shown) of an engine of a vehicle in the conventional manner.

[0011] The invention will be described with regard to the lower electromagnet 19. It will be appreciated, however, that the principles of the invention are applicable to the construction of the upper electromagnet 15 as well. Thus, with reference to FIG. 1, the lower electromagnet 15 includes a lamination stack, generally indicated at 14, which is contained in the lower housing 17. As shown in FIG. 2, the lamination stack 14 comprises a plurality of individual stacked laminations 16 preferably composed of a soft magnetic material such as silicon iron. Each lamination 16 is generally E-shaped defining channels 18 to receive a coil assembly 24 (FIG. 1) of the electromagnet 19. The individual laminations 16 are preferably joined by a weld 29, or other suitable method such as by pins or an interlocking arrangement to define the lamination stack 14. In accordance with the invention, each lamination 16 includes at least one shaped feature associated with a bottom surface 28 thereof which cooperate to define at least one shaped feature 26 of the lamination stack 14. In the illustrated embodiment, the shaped feature 26 includes two dovetails projecting in spaced relation from the bottom surface 28, used to secure the lamination stack 14 to the lower housing 17, as will become apparent below.

[0012] FIG. 3 shows the configuration of a cast lower housing 17 without the lamination stack 14 coupled thereto. As shown, the lower housing 17 includes at least one shaped feature 30 associated with the upper surface 32 thereof and constructed and arranged to mate with the shaped feature 26 of the lamination stack 14. In the illustrated embodiment, the shaped feature 30 of the lower housing 17 includes two spaced channels 30 defined in the upper surface 32 thereof to receive the dovetails 26 of the lamination stack 14.

[0013] For best possible heat transfer, the lamination stack 14 should be in intimate contact with the lower housing 17. This is best achieved by first placing the lamination stack inside a mold 34. The mold is configured to define the lower housing 17. Thus, the dovetails 26 of the lamination stack 14 define the shaped features 30 or channels in the lower housing 17 during the casting operation. In the illustrated embodiment, the lower housing 17 is composed of aluminum. However, it can be appreciated that other castable materials exhibiting good heat transfer properties can be employed as the material for the lower housing 17. Thus, aluminum is cast around the lamination stack 14 such that upon hardening of the aluminum, the dovetails 26 of the lamination stack 14 are engaged with the channels 30 of the lower housing 17 thereby joining the lamination stack 14 to the lower housing 17. FIG. 4 shows a cross-section of the lamination stack 14 joined to the lower housing 17 after the casting operation, with the upper surface of the lower housing 17 contacting the bottom

surface 28 of the lamination stack 14. After the aluminum has hardened, the assembly of the lower housing 17 and lamination stack 14 is removed from the mold.

[0014] It can be appreciated that instead of the providing the dovetail(s) 26 in the lamination stack 14 and channel(s) 30 in the lower housing 17, the lamination stack 14 can include the channel(s) and the lower housing 17 can include the mating dovetail(s).

[0015] Although the shaped features 26 of the lamination stack 14 were shown to be dovetails and the mating shaped features 30 of the lower housing 17 were shown to be channels, it can be appreciated that the mating shaped features 26 and 30 may be of other configurations to join the lamination stack 14 to the lower housing 17. For example, one of the components can include a groove and the other part can include a protrusion to be received in the groove.

[0016] Casting of the lamination stack 14 inside the housing 17 advantageously reduces machining operations necessary to prepare the housing for the lamination stack if the two components were to be assembled separately. Engagement of the lamination stack among its length by the housing provides added rigidity to the lamination stack, reducing deflection during operation of the actuator.

[0017] Further, since the dovetails 26 of the lamination stack 14 engage the channels 30 in the housing 17, and the generally planar upper surface 32 of the housing 17 contacts the generally planar bottom surface 28 of the lamination stack 17, good heat transfer between these two components is facilitated.

[0018] The foregoing preferred embodiments have been shown and described for the purposes of illustrating the structural and functional principles of the present invention, as well as illustrating the methods of employing the preferred embodiments and are subject to change without departing from such principles. Therefore, this invention includes all modifications encompassed within the spirit of the following claims.

## Claims

1. A method of joining a lamination stack of an electromagnetic actuator to a housing of the actuator, the method comprising:

providing a lamination stack having at least one shaped feature,

providing a mold to define the housing,

inserting the lamination stack into the mold such that said shaped feature of said lamination stack will define a mating shaped feature in said housing, and

casting material around at least a portion of said lamination stack to define said housing such that said shaped feature of said lamination stack is engaged with said shaped feature of said housing, thereby joining said lamination

stack to said housing.

2. The method according to claim 1, further comprising:

removing said lamination stack together with the housing from said mold.

3. The method according to claim 1, wherein said shaped feature of said lamination stack comprises one of a dovetail and a channel, and said shaped feature of said housing includes the other of said dovetail and said channel.

4. The method according to claim 3, wherein said shaped feature of said lamination stack includes a dovetail and said shaped feature of said housing includes a channel receiving said dovetail.

5. The method according to claim 4, wherein a pair of dovetails extend in spaced relation from a bottom surface of said lamination stack which mate with a pair of channels in said housing.

6. The method according to claim 1, wherein aluminum is cast in the mold to define said housing.

7. The method according to claim 1, wherein said lamination stack is provided by joining a plurality of individual lamination together, each of said individual laminations having a shaped feature which cooperate to define said shaped feature of said lamination stack.

8. The method according to claim 1, wherein said shaped feature of said lamination stack is associated with a bottom surface of said lamination stack and said shaped feature of said housing is associated with an upper surface of said housing, and said casting is such that said when said shaped features are engaged, said upper surface of said housing contacts said bottom surface of said lamination stack.

9. The method according to claim 1, wherein a plurality of shaped features are provided on the lamination stack and a corresponding number of mating shaped features are defined in the housing upon casting said material.

10. A lamination and housing assembly for an electromagnetic actuator comprising:

a lamination stack comprising a plurality of individual laminations, said lamination stack including a bottom surface and a shaped feature associated with said bottom surface, and a housing having an upper surface and a

shaped feature associated with said upper surface, said housing receiving said lamination stack such that said shaped feature of said lamination stack is engaged with said shaped feature of said housing, with said bottom surface of said lamination stack contacting said upper surface of said housing.

11. The assembly according to claim 10, wherein said shaped feature of said lamination stack includes a dovetail and said shaped feature of said housing includes a channel receiving said dovetail.

12. The assembly according to claim 10, wherein each of said individual laminations is of generally E-shape.

13. The assembly according to claim 10, wherein said bottom surface of said lamination stack and said upper surface of said housing are each generally planar.

14. The assembly according to claim 10, wherein said laminations are made of magnetic material and said housing is composed of aluminum.

15. The assembly according to claim 10, wherein a plurality of shaped features are provided on said lamination stack and a corresponding number of shaped features are provided on said housing.

FIG. 1

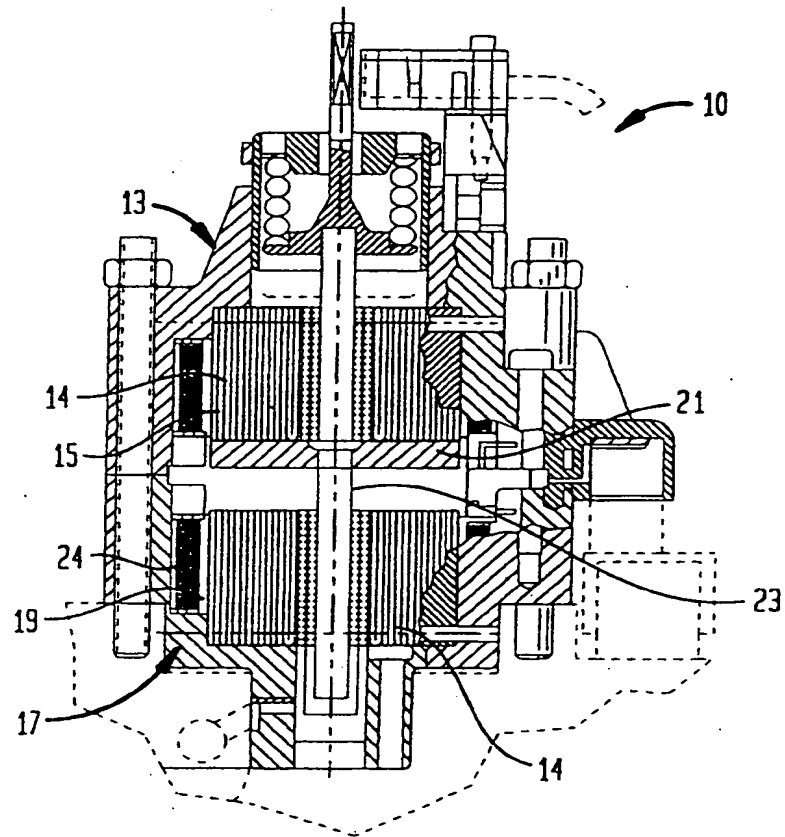


FIG. 2

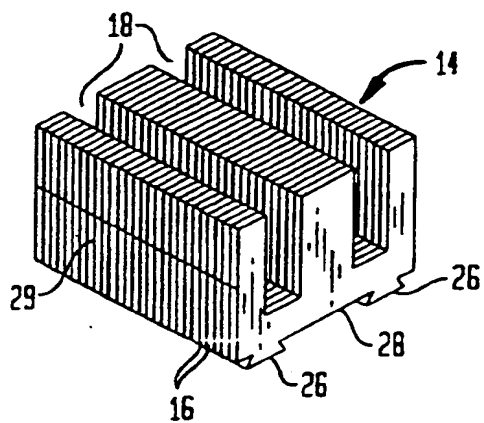


FIG. 3

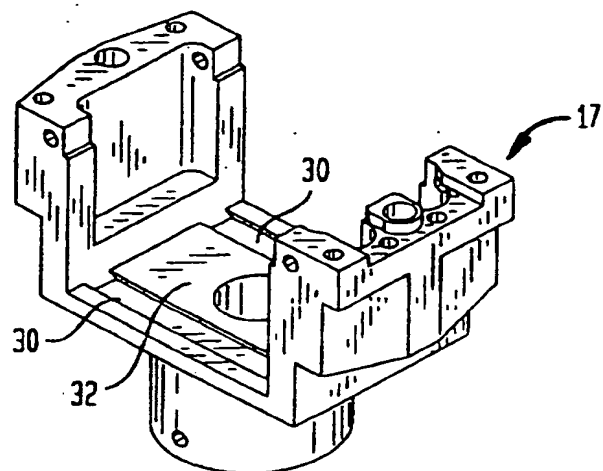
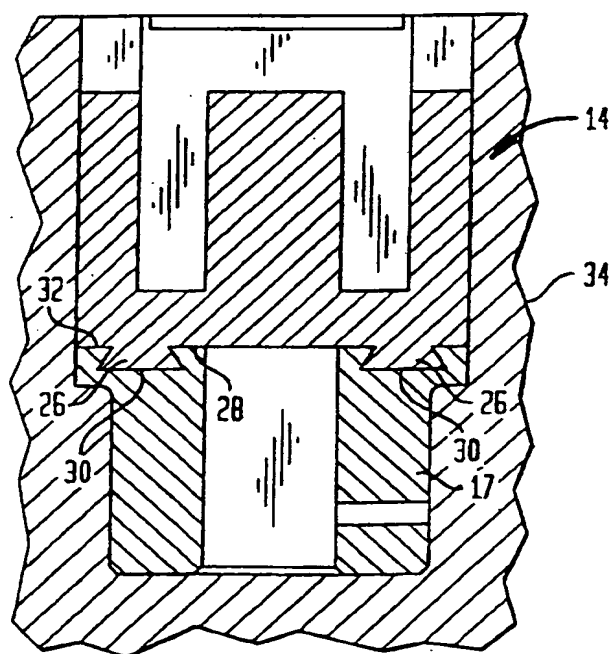


FIG. 4





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# EUROPEAN SEARCH REPORT

Application Number  
EP 98 12 3223

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 4 540 966 A (ZELKOWITZ PHILLIP) 10 September 1985 * column 3, line 61 - column 4, line 3 *	1-4, 6-8, 10, 11, 14	H01F7/06 H01F7/08 F01L9/04 H01F7/16
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 10 March 1999	Examiner Vanhulle, R
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EPO FORM 1503 03/02 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT  
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EP 98 12 3223

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on  
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